EarthCARE – Final Preparations for the Earth Cloud, Aerosol and Radiation Explorer

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Linking Clouds, Aerosol and Radiation

Science: Impact of Clouds and Aerosols on Radiation

Observations:

- Cloud profiles (ice, liquid, mixed), cloud coverage, precipitation
- Aerosol profiles
- Broad-band Solar & Thermal Radiation

Satellite and Payload

- Sun-sync. orbit at 393 km, 14:00 hours descending node
- UV Lidar with high spectral resolution receiver
- W-band Cloud Radar with Doppler (contribution JAXA)
- Imager and Broad-Band Radiometer
- Launch 2023

Earth Explorer Mission implemented in cooperation with JAXA

Cloud Profiling Radar (CPR) - JAXA

94 GHz Doppler, 2.5 m dish (folded in photograph)

Level 1: Reflectivity and Doppler profiles

Atmospheric Lidar (ATLID)

High-Spectral Resolution Lidar (HSRL), λ=355nm

Two redundant transmit telescopes & 60 cm receive tel.

3 receive channels: molecular, particular, depolarization

Level 1: attenuated backscatter profiles

Multi-Spectral Imager (MSI)

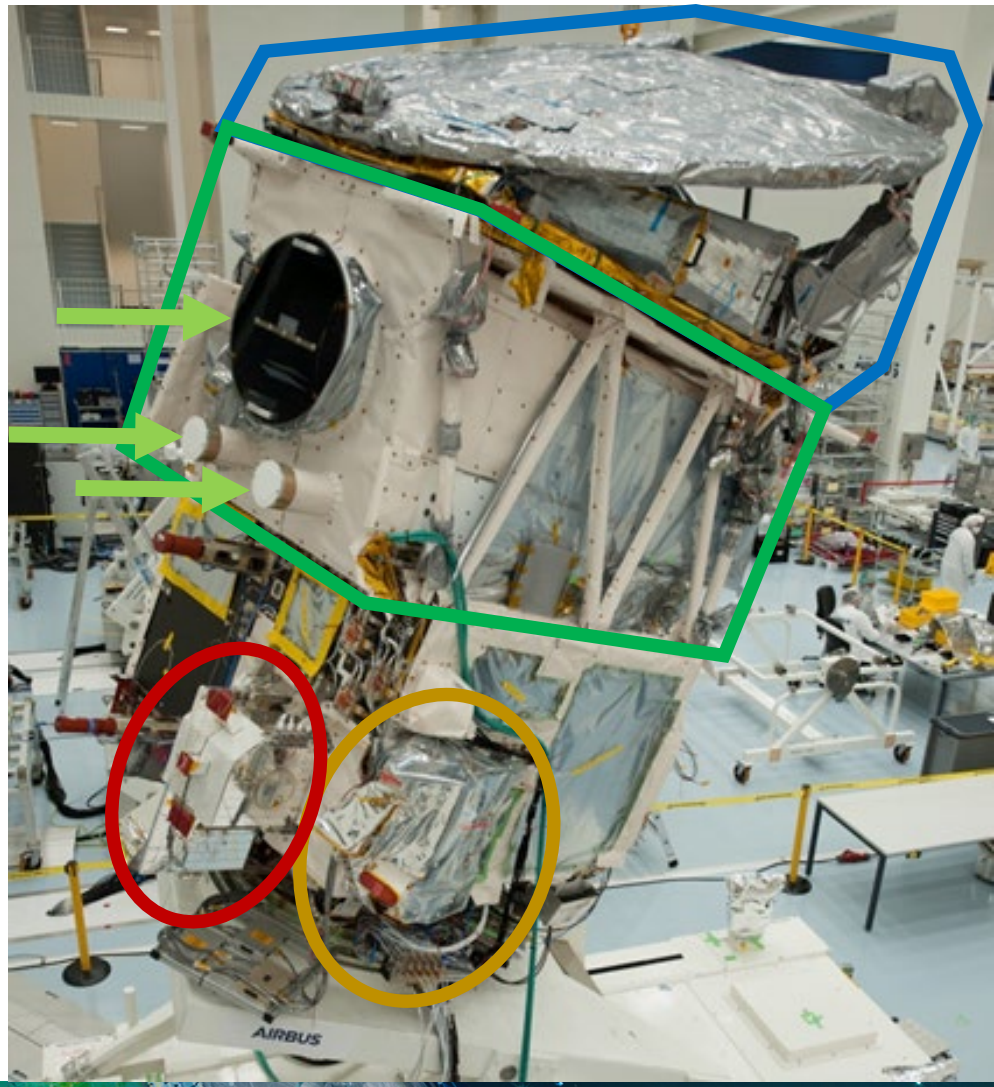
pushbroom, 4 solar + 3 TIR channels

Level 1: TOA radiances and brightness temperatures

Broad-Band Radiometer (BBR)

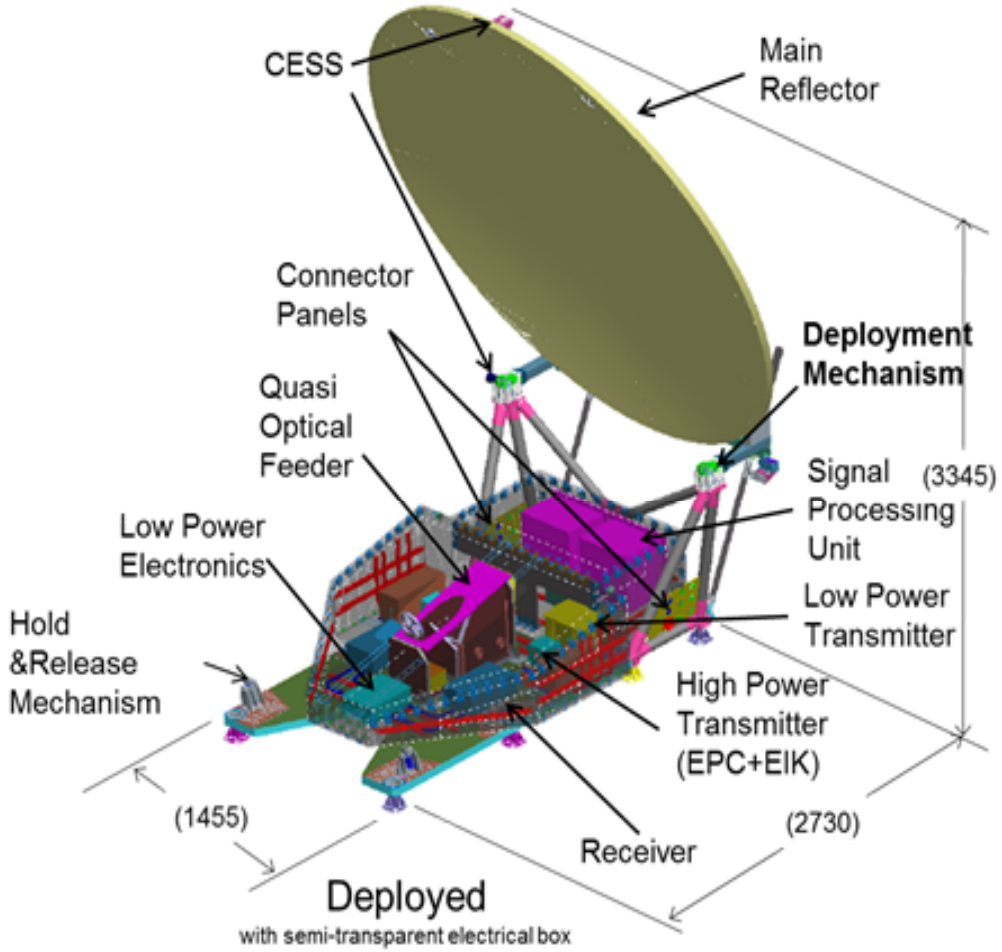
2 Channels: Solar + Thermal; 3 fixed FoV

Level 2: TOA solar and thermal radiances & fluxes



Photos courtesy Airbus

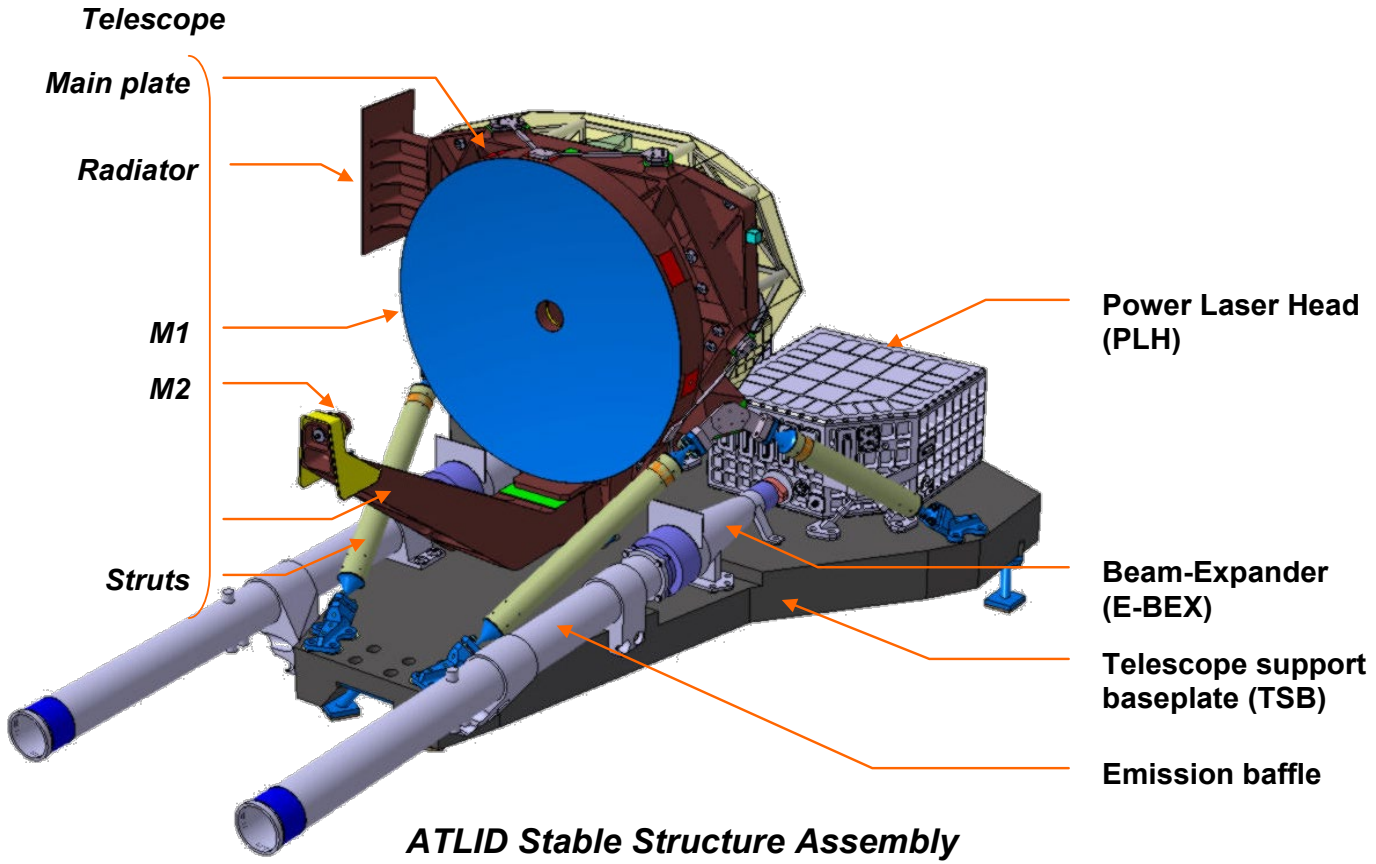
The Cloud Profiling Radar – CPR



- High power W-band (94GHz), nadir-pointing
- Doppler capability
- Antenna aperture 2.5m
- Variable PRF: 6100-7500 Hz
- Sensitivity at least -35dBZ at 20km height
- Sampling: 500m horizontal, 100m vertical
- Vertical range up to 12, 16 or 20km as function of latitude. Lower vertical range → higher PRF → better Doppler
- -3dB beamwidth = 0.09˚ → effective footprint on ground = 750m x 1000m
- Instrument: 321 W, 270 kg, 265 kbps
- Level 1 product: reflectivity & Doppler profiles

The Atmospheric Lidar – ATLID

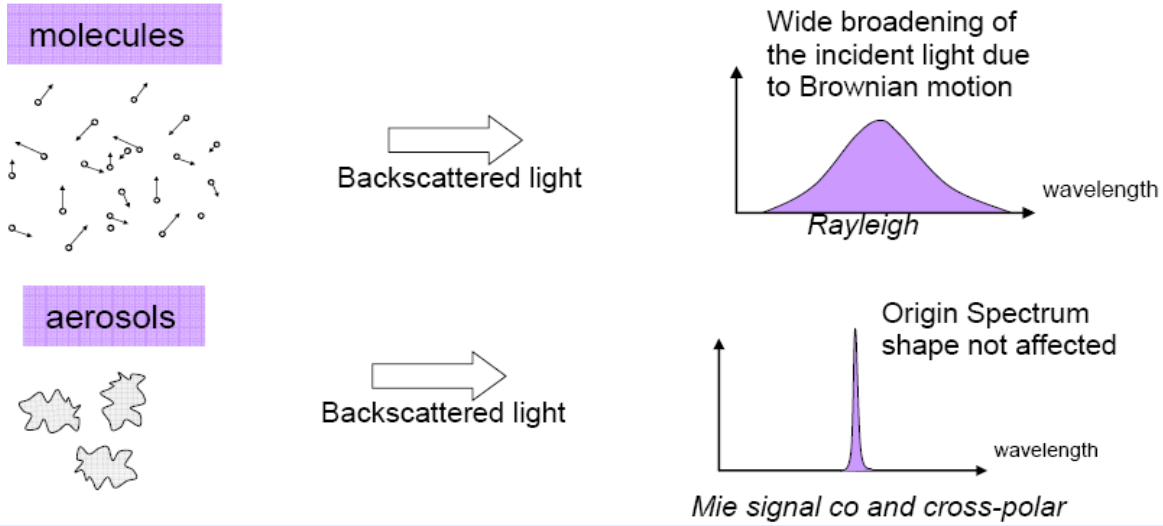
- Atmospheric Lidar
  laser wavelength λ = 355nm, lin. pol.
- High Spectral Resolution Lidar (HSRL) using Fabry-Perot etalon centred on the laser centre wavelength → separates molecular from particle backscatter signals (lidar ratio measured)
- 3 channels receiver :
  - Rayleigh scatter
  - co-polar Mie
  - cross-polar
- Main products are profiles of
  - molecular backscatter signal
  - cloud and aerosol backscatter signal, co-polar
  - cloud and aerosol backscatter signal, cross-polar
  - extinction
- Sampling: along-track 290m (2x integrated), vertical 103m (up to 20km)
- Mass: 558 kg, Power: 585 W, Data rate <660 kb/s

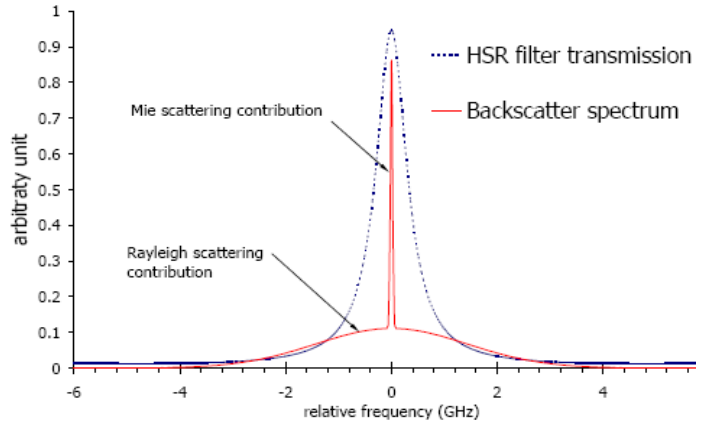


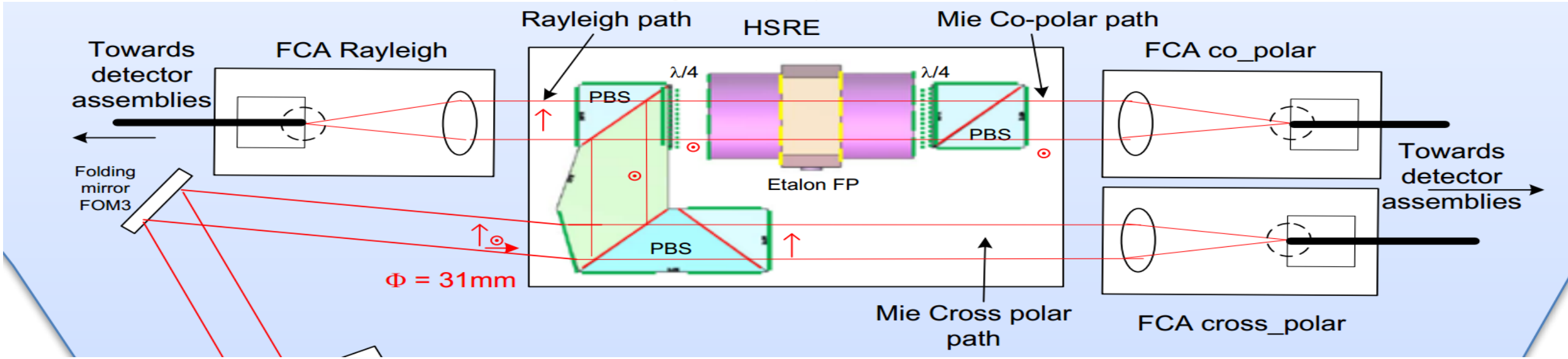
ATLID Stable Structure Assembly (SSA) and equipments

Industry: Airbus (F) + Selex ES (I)

ATLID


molecules
Backscattered light
Wide broadening of the incident light due to Brownian motion
wavelength
Rayleigh
aerosols
Backscattered light
Origin Spectrum shape not affected
wavelength
Mie signal co and cross-polar


HSR filter transmission
Backscatter spectrum
Mie scattering contribution
Rayleigh scattering contribution
arbitraty unit
relative frequency (GHz)


Towards detector assemblies
FCA Rayleigh
Rayleigh path
HSRE
Mie Co-polar path
FCA co_polar
λ/4
PBS
λ/4
PBS
Etalon FP
Folding mirror FOM3
PBS
Towards detector assemblies
Φ = 31mm
Mie Cross polar path
FCA cross_polar

Multi-Spectral Imager – MSI

Objective:

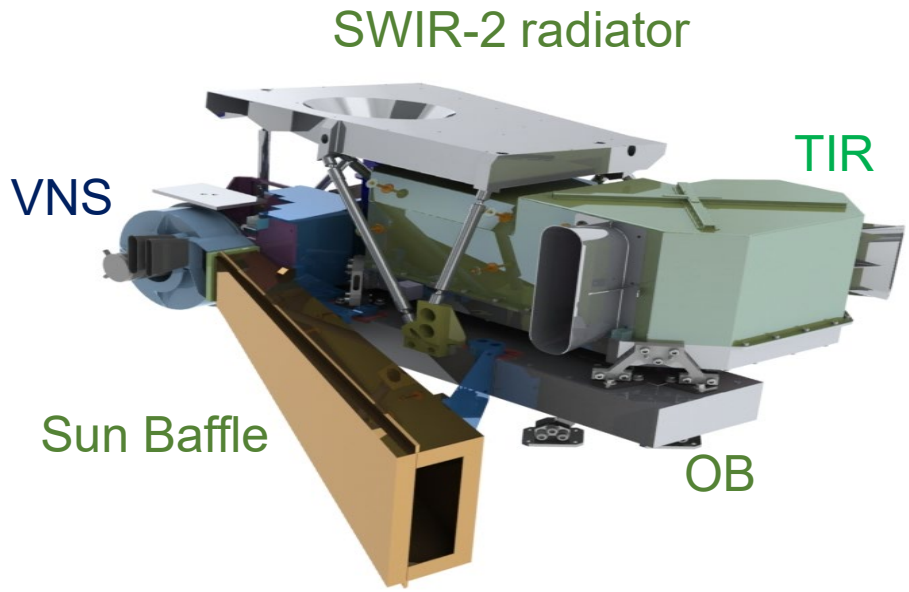
To provide contextual imagery information to support the retrievals of geophysical parameters by the active instruments on-board EarthCARE

Characteristics:

150 km swath (-35km to +115 km)
500 m ground sampling distance
57 W, 60 kg, 652 kbps

Level 1 product: radiances (VNS) & brightness temperatures (TIR)

Industry: SSTL (UK) + TNO (NL)



Signal to noise
VIS/NIR 70-500
SWIR 20-250
Noise (NEDT)
TIR 0.25-0.80 K

Channel	Centre Wavelength [µm]	Bandwidth (50%) [µm]
VIS	0.67	0.02
NIR	0.865	0.02
SWIR 1	1.65	0.05
SWIR 2	2.21	0.1
TIR 1	8.8	0.9
TIR 2	10.8	0.9
TIR 3	12.0	0.9

Broad-Band Radiometer – BBR

Three fixed telescopes:
forward (55˚), nadir, backward (-55˚)

Two channels:
Short-wave (SW) channel 0.25 µm to 4 µm
Total-wave (TW) channel 0.25 µm to >50 µm
→ Long-wave (LW) derived from TW-SW

Abs. accuracy 2.5 (SW) / 1.5 (LW) $Wm^{-2}sr^{-1}$

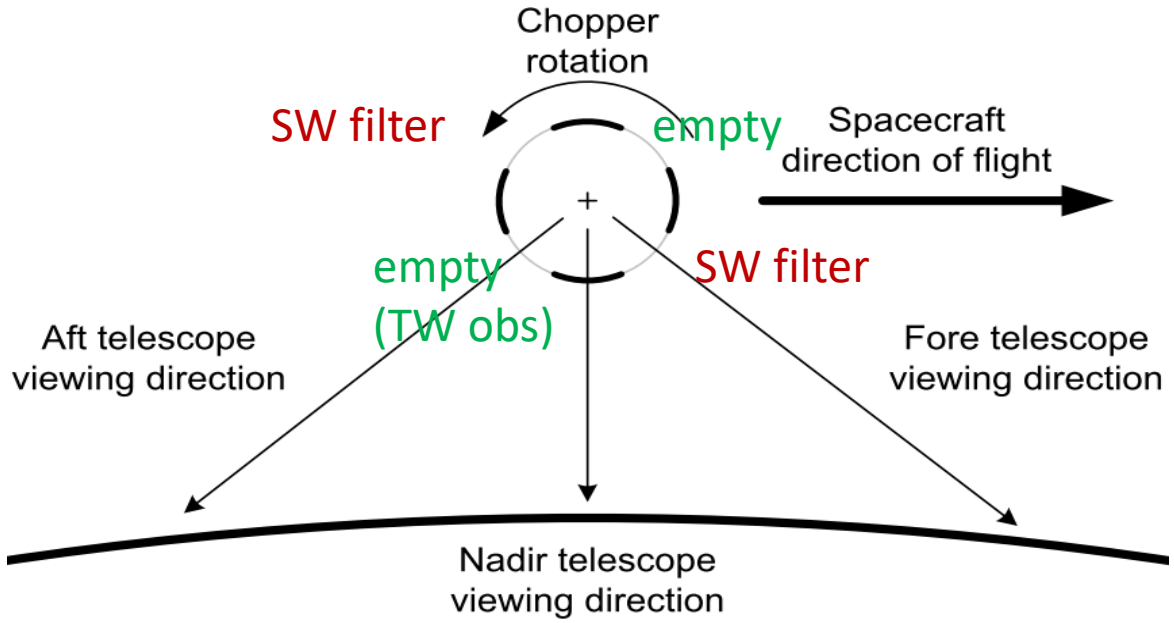
Spatial resolution nominal 10 km x 10 km

Spatial sampling distance 1 km

48 W, 45 kg, 145 kbps

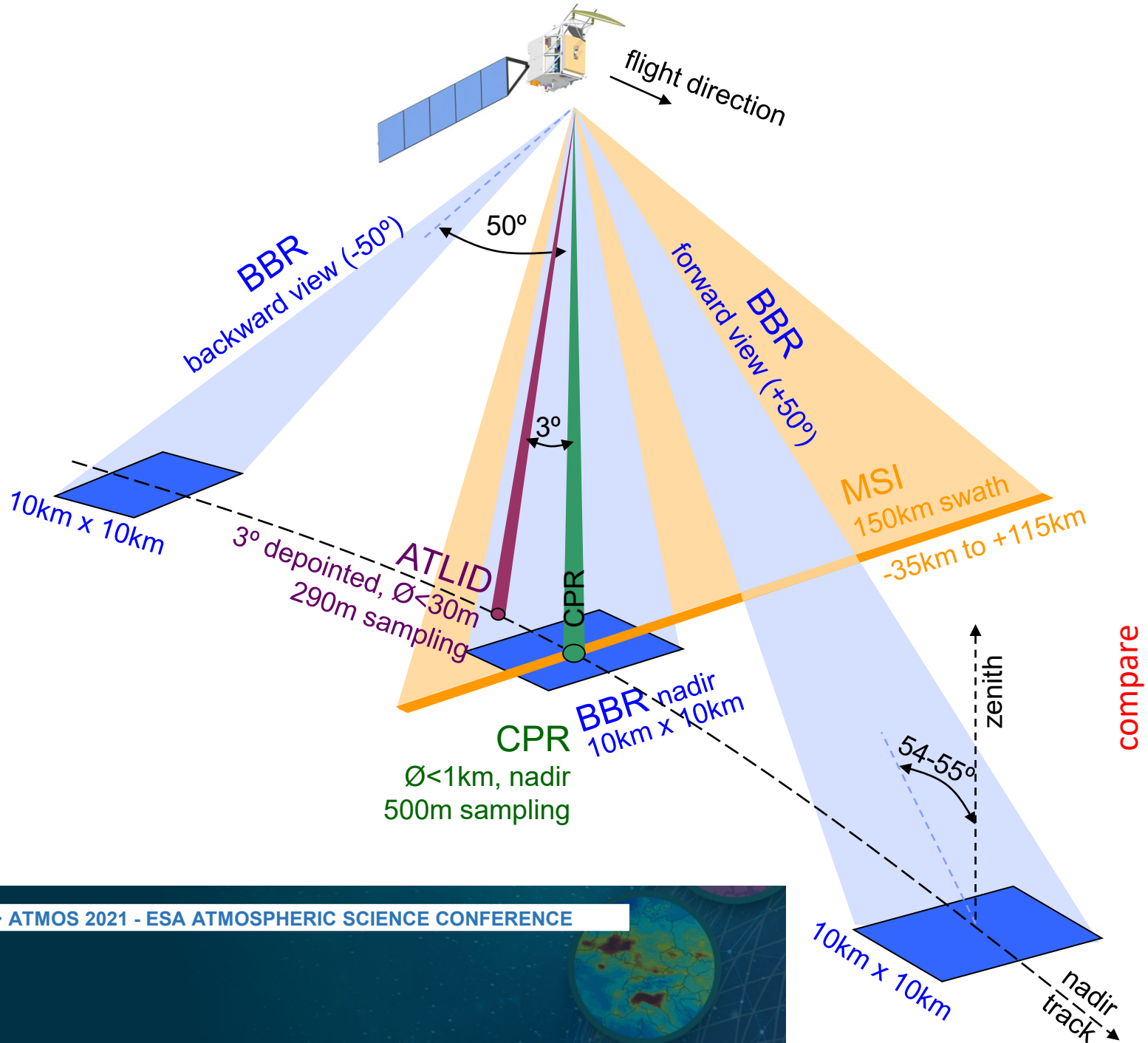
Products: TOA SW/LW radiances & flux

Industry: TAS (UK) + RAL (UK)



3 fixed, single mirror telescopes, each with a linear microbolometer detector array.
Chopper drum rotates continuously, chopping the signal between SW, drum & TW views
Calibration drum periodically rotates into view:

- Hot or cold blackbody, every 88s, to calibrate LW
- View to sun diffuser, every 2 months for 30 orbits, to monitor aging in the SW chain



Radar science products:
vertical profiles of (thick) clouds, precip.

Lidar science products:
vertical profiles of (thin) cloud & aerosol

Imager science products:
across-track scene context,
2D cloud & aerosol information

Synergy products:

- Cloud-precip-aerosol vertical profiles
- 3D cloud & aer. scenes (100km^2)
- calculated TOA radiances & fluxes
- calculated heating rates

compare

Radiometer science products:
TOA radiances and fluxes

Data volume

Data volume estimate

(Total L0 up to L2b)

ESA: 60 GB / orbit

JAXA: 11 GB / orbit

Data latency

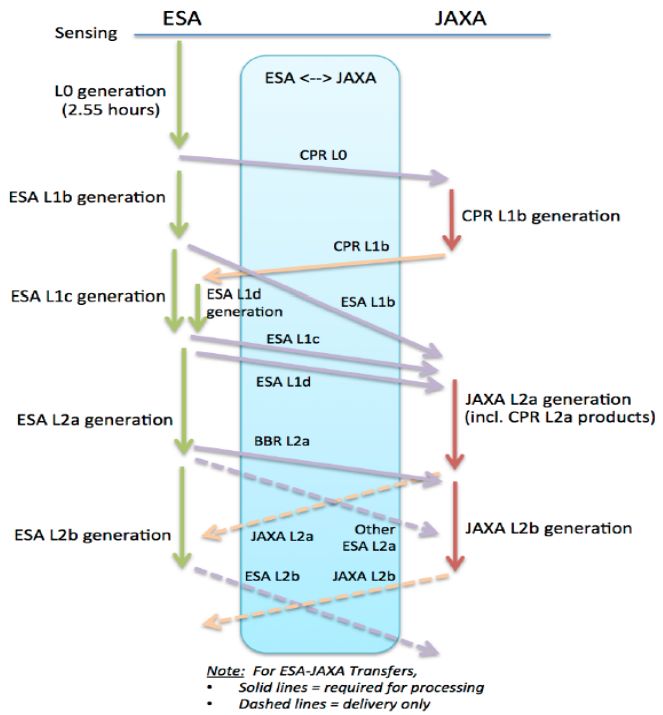
Nominal (60% of data):

Within 5.5 h from sensing

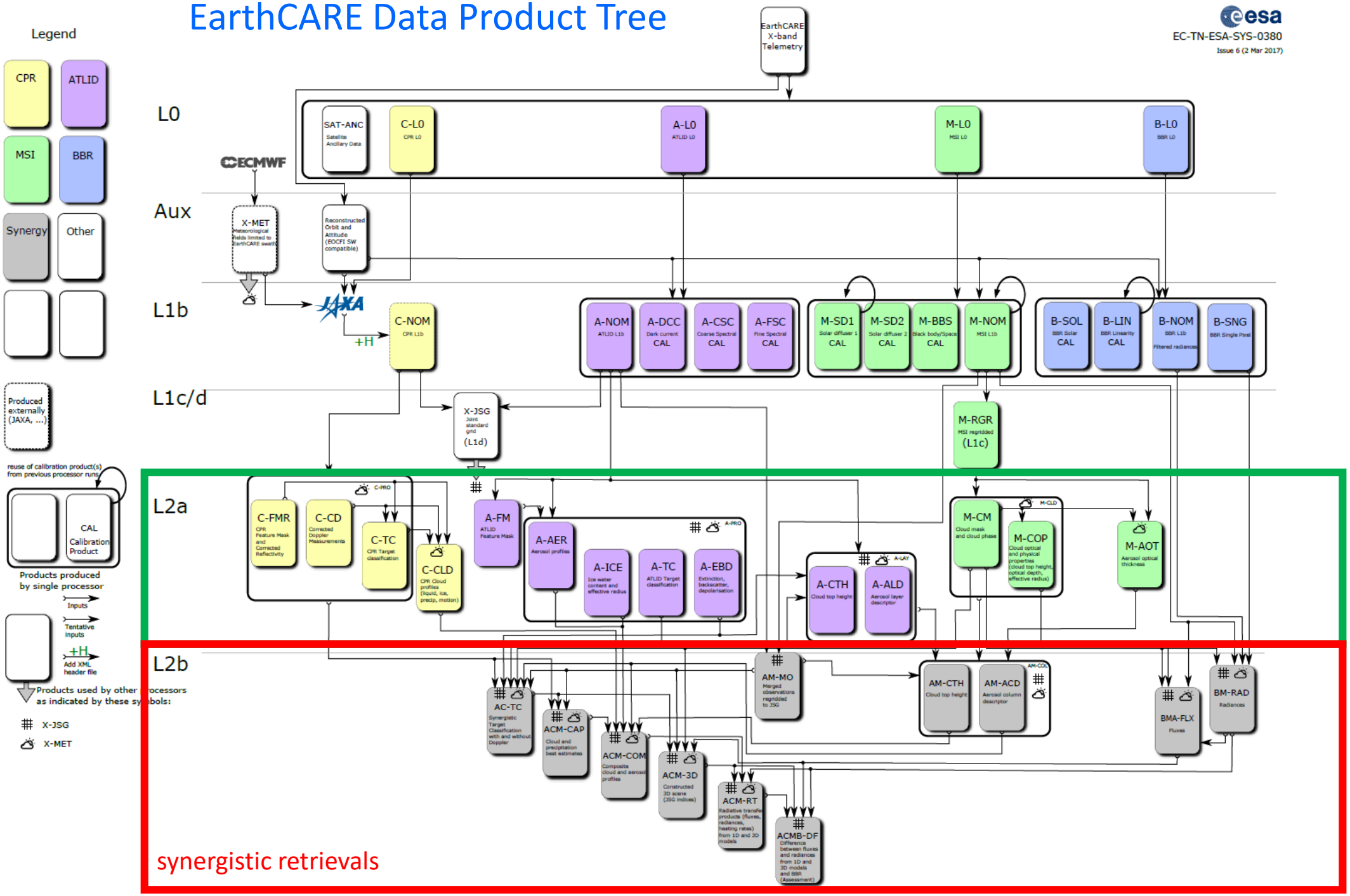
Worst case (blind orbits):

24h (up to L2a)/48h (L2b)

(MB per orbit)		ATLID	CPR	MSI	BBR	TOTAL
Level 0		621	221	485	103	1,430
Level 1b		6,000	640	5,500	150	12,290
Level 1c				1,200		1,200
Level 1d (X-JSG and X-MET)						4,900
Level 2a	ESA	7,400	3,000	10,800	20	21,220
	JAXA	870	3,045	2,010		5,925
Level 2b (Radiation)		6,000				6,000
Level 2b (Cloud/Aerosol)		11,000				11,000
JAXA Level 2b		3,369				3,369
Volume Margins	ESA	2,600				2,600
	JAXA	1,066				1,066
TOTAL DATA VOLUME / ORBIT						***71,000***
TOTAL DATA VOLUME / ORBIT (ESA → JAXA)						*60,000*
TOTAL DATA VOLUME / ORBIT (JAXA → ESA)						*11,000*

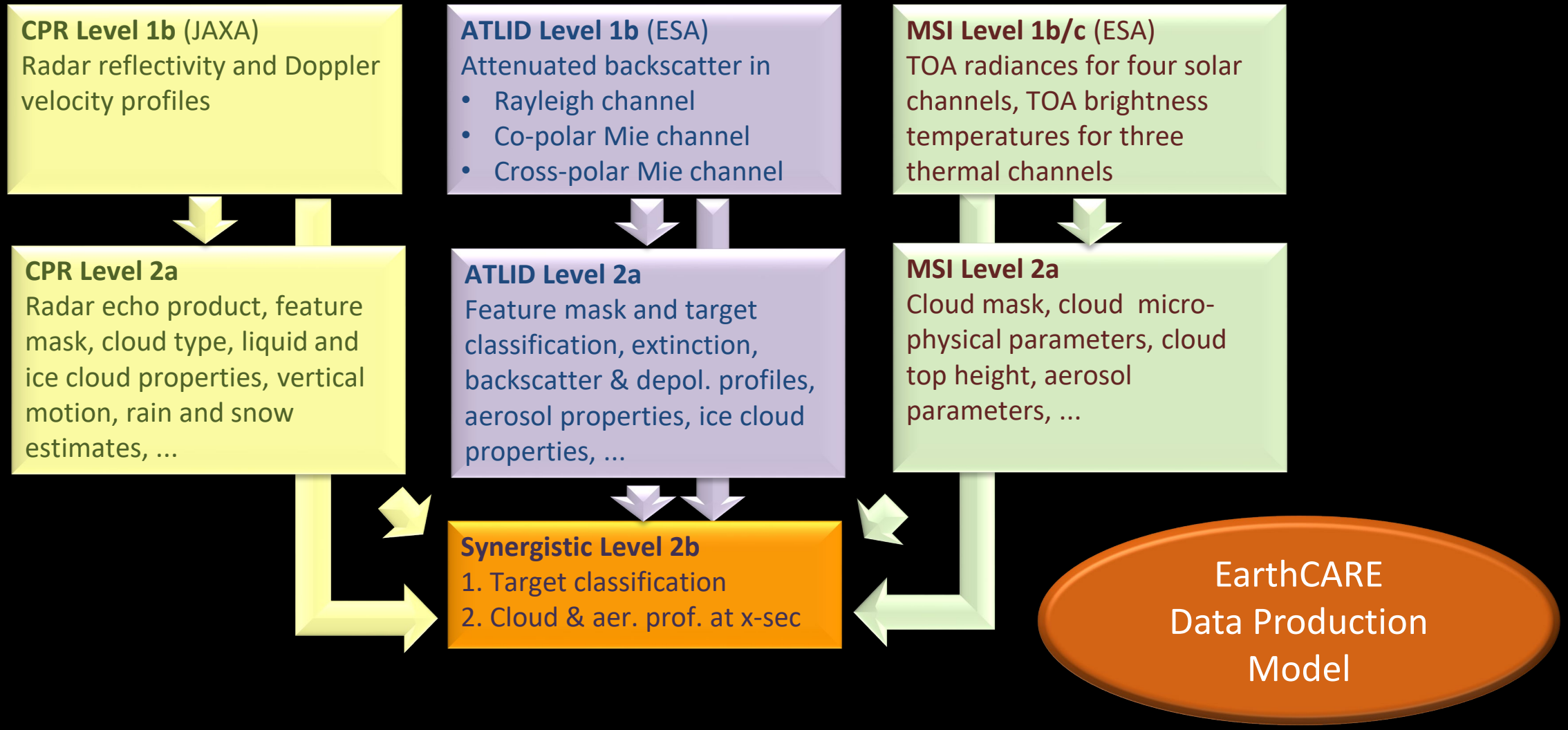


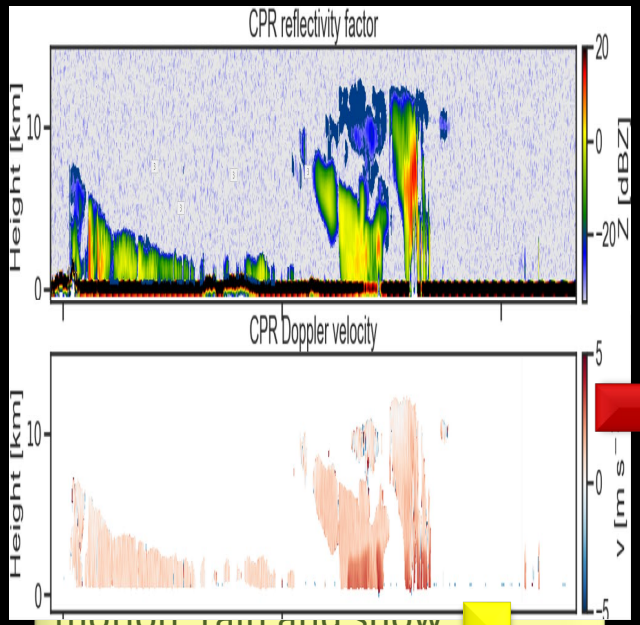
EarthCARE Data Product Tree

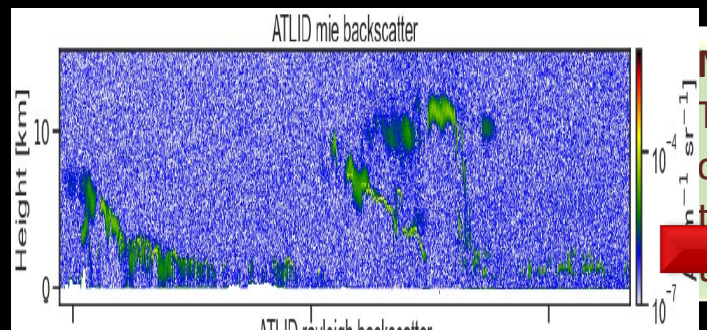


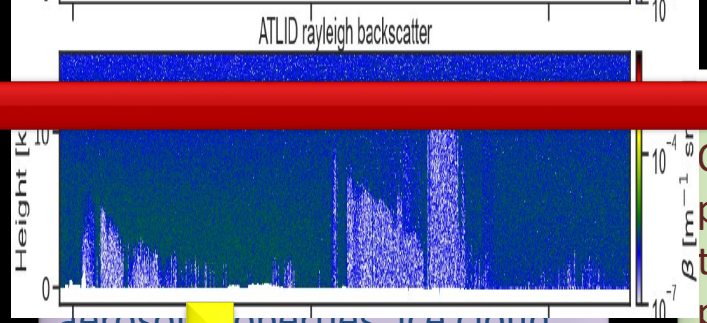
ESA data products will be produced operationally by the ESA ground segment located at ESRIN.

JAXA data products fall in two categories: **Standard Products**: produced and released by JAXA Mission Operation System: (1) CPR echo and cloud products; (2) ATLID feature & target mask, aerosol & cloud products, PBL height; (3) MSI cloud products; (4) CPR-ATLID synergistic cloud products; (5) CPR-ATLID-MSI synergistic cloud products; (6) Four-sensor synergy radiative products. **Research Products:** processed by either JAXA/EORC or co-operating Japanese Laboratories, are single or multi-sensor cloud, aerosol, precipitation, snow and air motion products.


CPR Level 1b (JAXA)
Radar reflectivity and Doppler velocity profiles
ATLID Level 1b (ESA)
Attenuated backscatter in
• Rayleigh channel
• Co-polar Mie channel
• Cross-polar Mie channel
MSI Level 1b/c (ESA)
TOA radiances for four solar channels, TOA brightness temperatures for three thermal channels
CPR Level 2a
Radar echo product, feature mask, cloud type, liquid and ice cloud properties, vertical motion, rain and snow estimates, ...
ATLID Level 2a
Feature mask and target classification, extinction, backscatter & depol. profiles, aerosol properties, ice cloud properties, ...
MSI Level 2a
Cloud mask, cloud micro-physical parameters, cloud top height, aerosol parameters, ...
Synergistic Level 2b
1. Target classification
2. Cloud & aer. prof. at x-sec
EarthCARE Data Production Model







MSI Level 1b

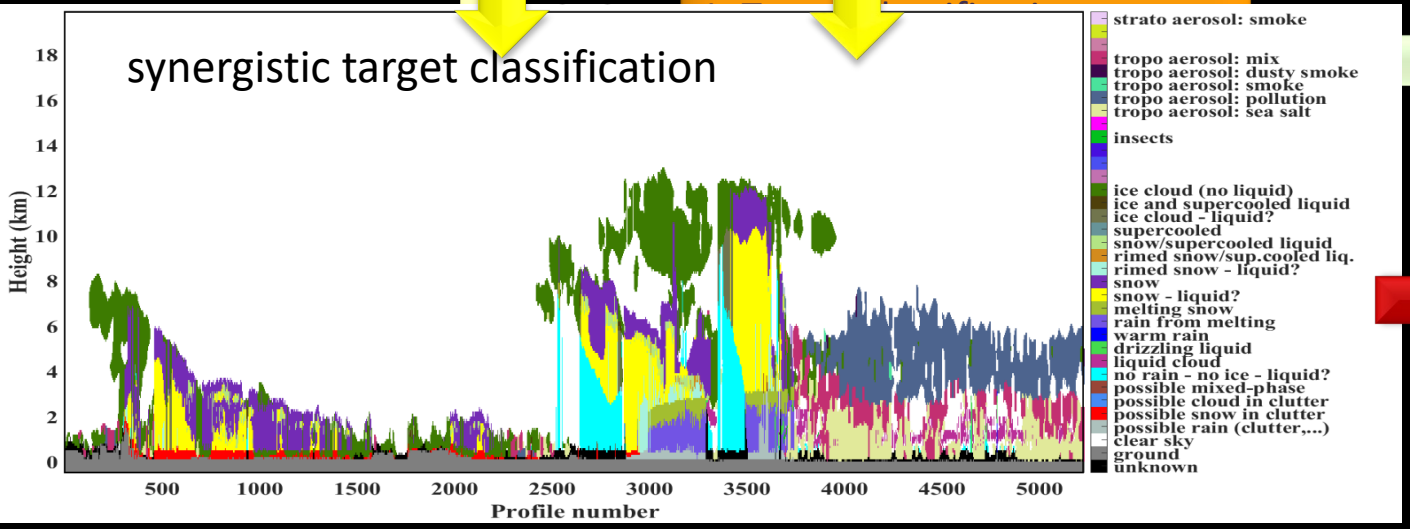
TOA radiance
channels, TOA
temperature
thermal chan

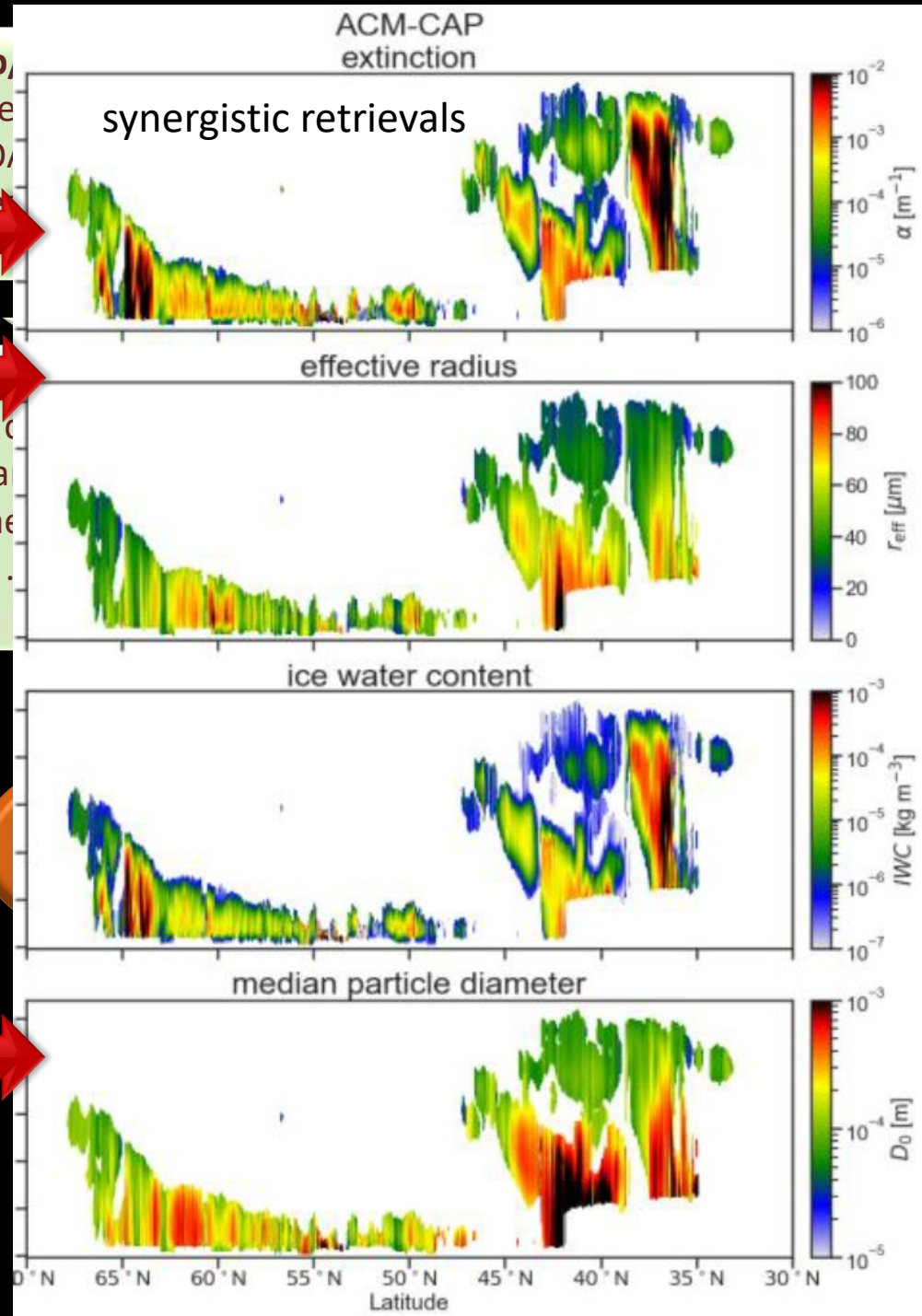
Cloud mask, c
physical para
top height, ae
parameters, .

motion, rain and snow
estimates, ...

aerosol properties, ice cloud
properties, ...

Synergistic Level 2b





acknowledgements: KNMI, LATMOS, ECMWF

CPR Level 1b (JAXA)
Radar reflectivity and Doppler velocity profiles

ATLID Level 1b (ESA)
Attenuated backscatter in
- Rayleigh channel
- Co-polar Mie channel
- Cross-polar Mie channel

MSI Level 1b/c (ESA)
TOA radiances for four solar channels, TOA brightness

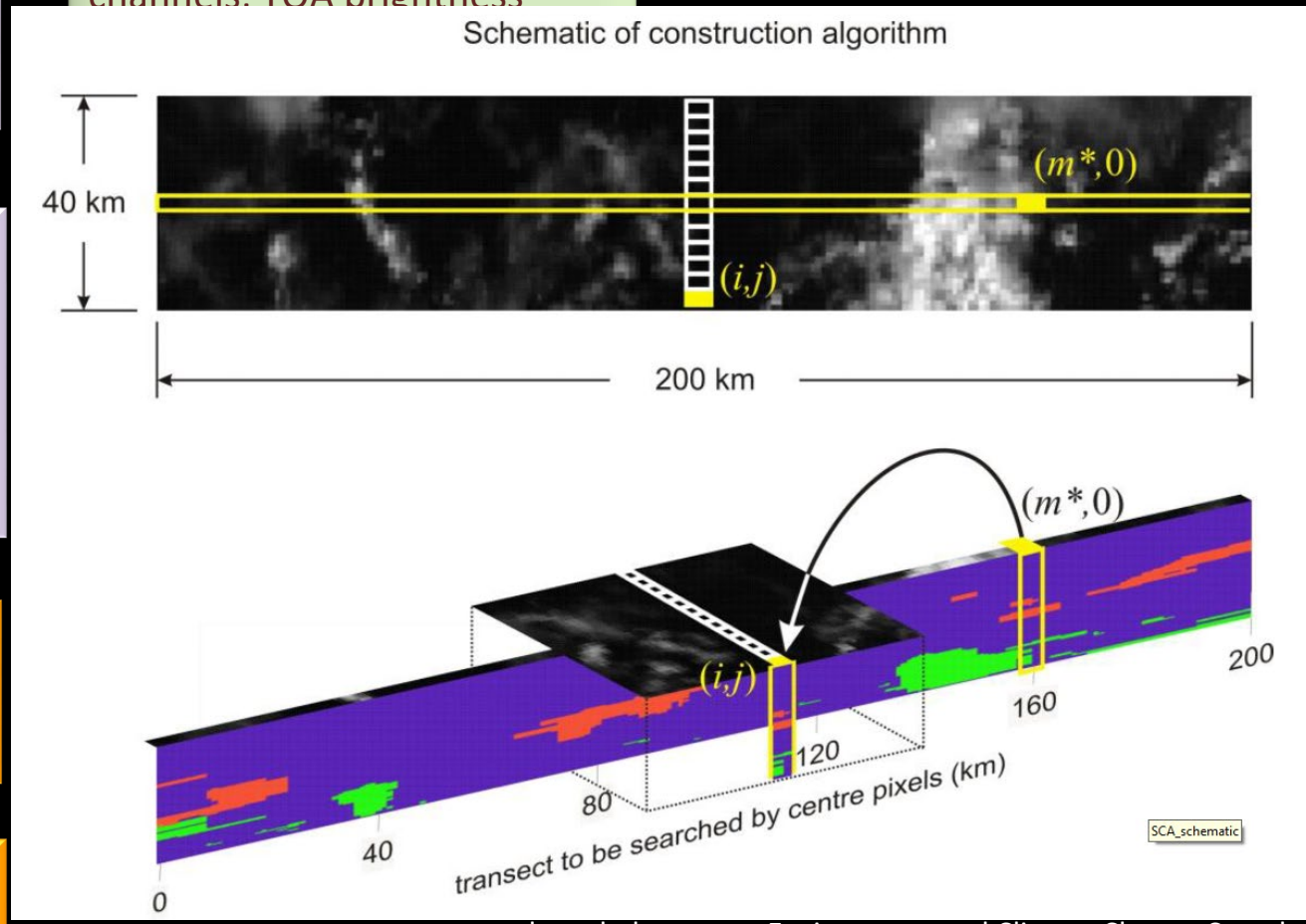
CPR Level 2a
Radar echo product, feature mask, cloud type, liquid and ice cloud properties, vertical motion, rain and snow estimates, ...

ATLID Level 2a
Feature mask and target classification, extinction, backscatter & depol. profiles, aerosol properties, ice cloud properties, ...

Synergistic Level 2b
1. Target classification
2. Cloud & aer. prof. at x-sec

3D Scenes Construction
Expand syn. retrievals across-track using MSI; ≈40km wide

Radiative Transfer Products
calculated radiances, fluxes, heating rate profiles



acknowledgements: Environment and Climate Change Canada

CPR Level 1b (JAXA)
Radar reflectivity and Doppler velocity profiles

ATLID Level 1b (ESA)
Attenuated backscatter in
- Rayleigh channel
- Co-polar Mie channel
- Cross-polar Mie channel

MSI Level 1b/c (ESA)
TOA radiances for four solar channels, TOA brightness temperatures for three thermal channels

BBR Level 1b (ESA)
Filtered TOA short-wave and total-wave radiances

CPR Level 2a
Radar echo product, feature mask, cloud type, liquid and ice cloud properties, vertical motion, rain and snow estimates, ...

ATLID Level 2a
Feature mask and target classification, extinction, backscatter & depol. profiles, aerosol properties, ice cloud properties, ...

MSI Level 2a
Cloud mask, cloud micro-physical parameters, cloud top height, aerosol parameters, ...

BBR Level 2a
Unfiltered top-of-atmosphere radiances, short-wave and long-wave fluxes
BBR Level 2b: enhanced products using MSI

Synergistic Level 2b
1. Target classification
2. Cloud & aer. prof. at x-sec

EarthCARE Data Production Model

3D Scenes Construction
Expand syn. retrievals across-track using MSI; ≈40km wide

Radiative Transfer Products
calculated radiances, fluxes, heating rate profiles

Assessment
Comparison of calculated fluxes and radiances to BBR observations

Retrievals and "Closure"

Example of work in progress

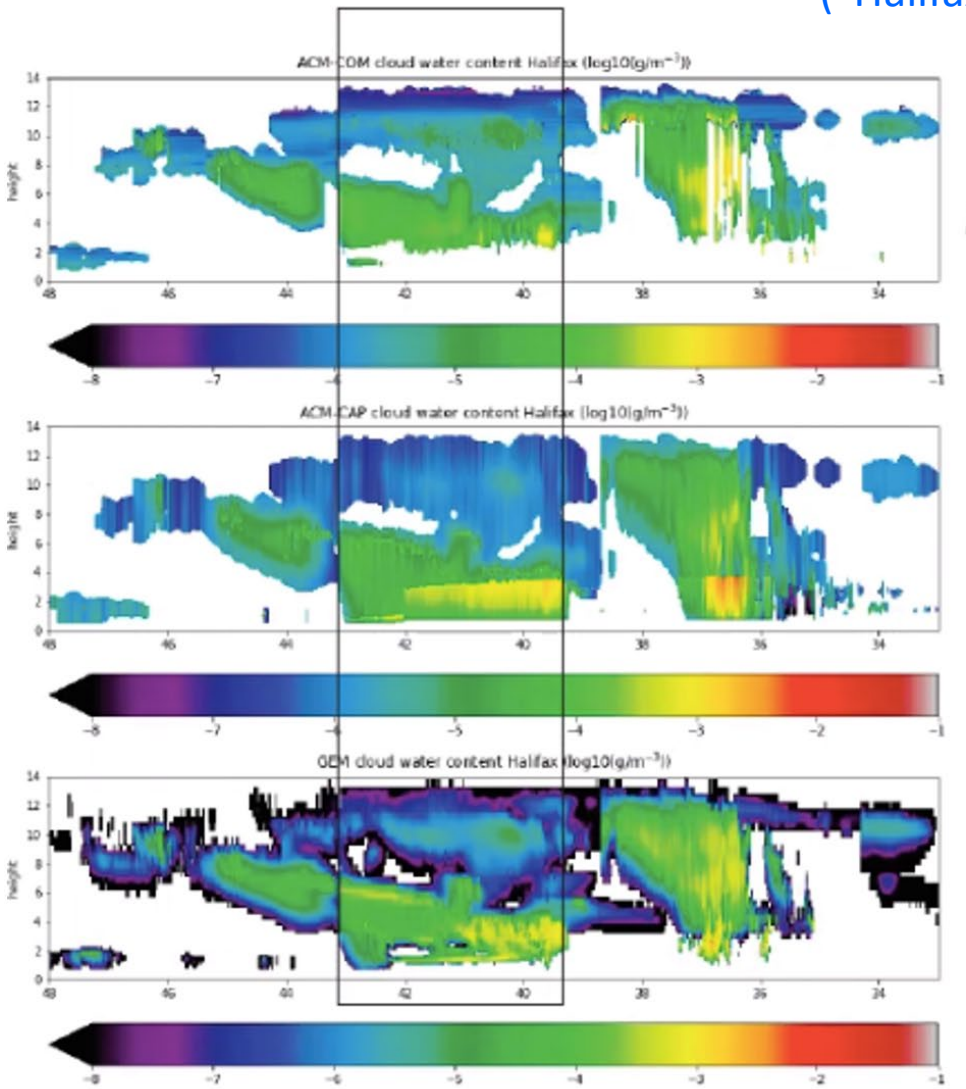
Reconstructed cloud scene based on radar-only + lidar-only + imager-only cloud retrievals ("Composite" product)
FLUX IN BLUE

Synergistically retrieved cloud scene, CAPTIVATE algorithm (Opt. Estimation with complex state vector)
FLUX IN YELLOW

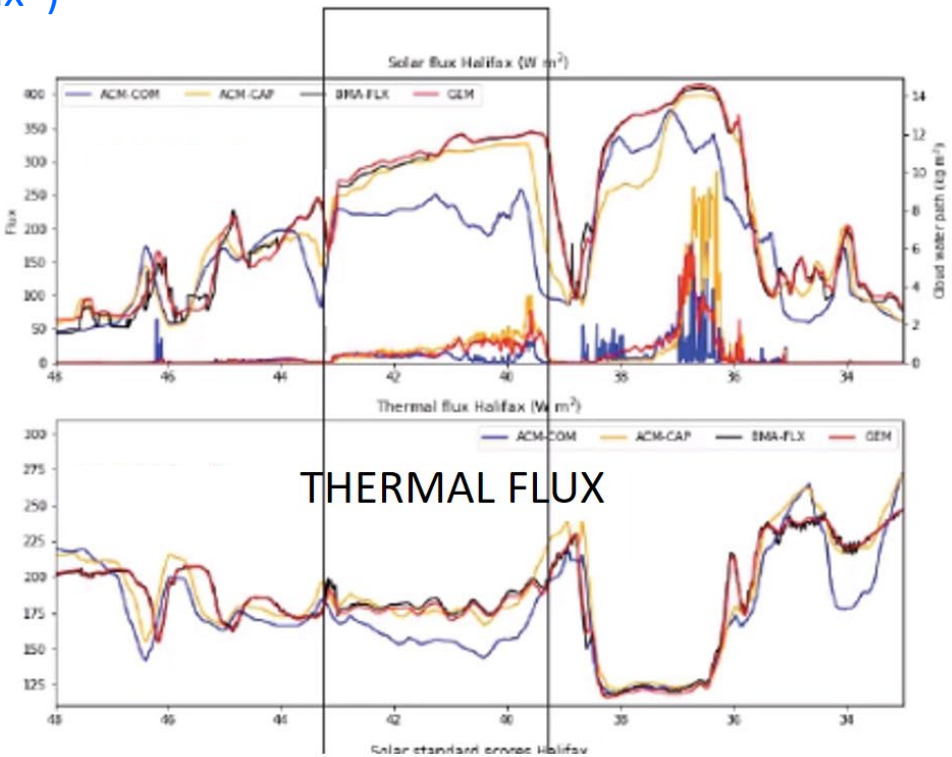
Model truth (Canadian Weather Model GEM)
FLUX IN RED

Cloud water content

Test Scene ("Halifax")



SOLAR FLUX



→ "Composite" clouds are too dull and too cold

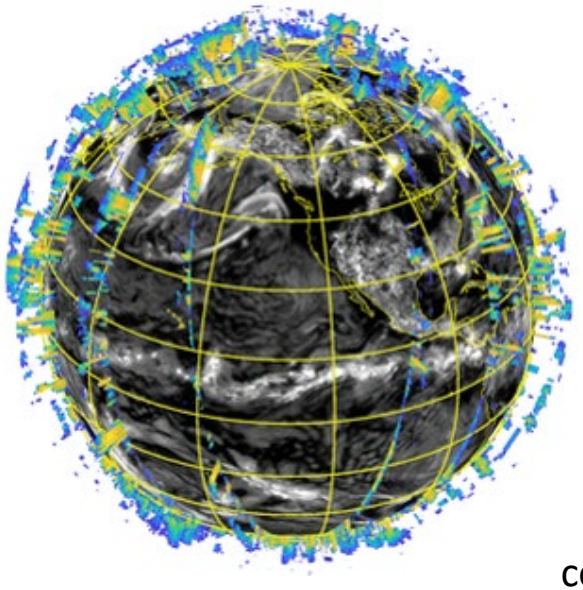
Acknowledgement
R. Hogan, S. Mason, H. Barker, Y. Cole, Z. Qu, D. Donovan

Assimilation of EarthCARE cloud radar and lidar

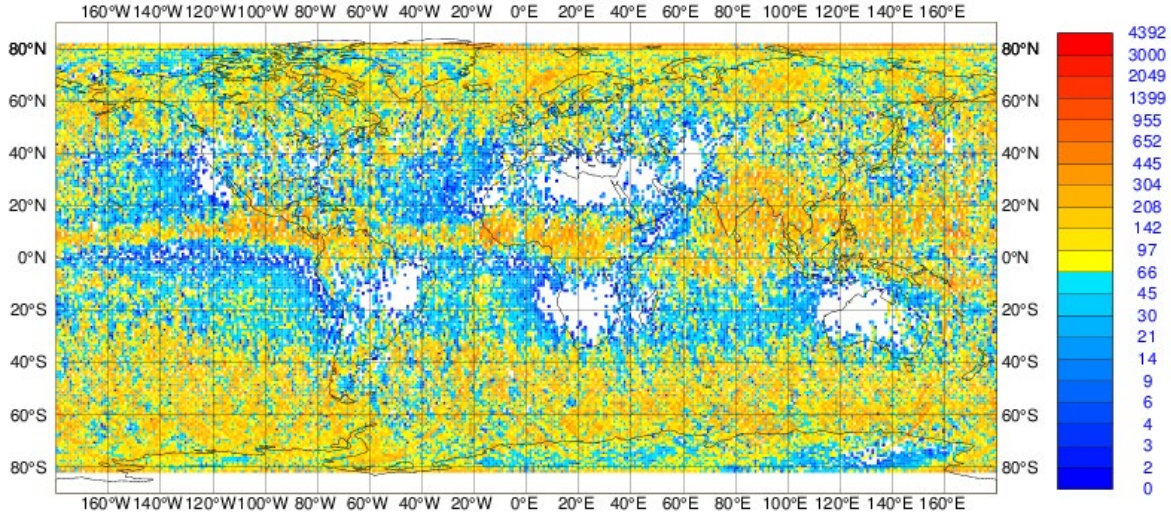
Preparation for data monitoring and assimilation into operational model progressing at ECMWF

1. Monitoring of data quality in near real-time against the operational model
2. Model-to-observation evaluation of cloud and precipitation and subsequent model development
3. Potential for improving the model analysis leading to direct improvements of forecast skill demonstrated
4. Radar reflectivity, Lidar backscatter. New work towards utilisation of radar Doppler velocity, Lidar Mie channel extinction and Rayleigh channel attenuated backscatter (monitoring)

Expected data coverage for 12 hours



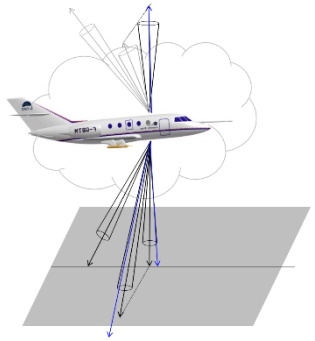
Expected data coverage for one month

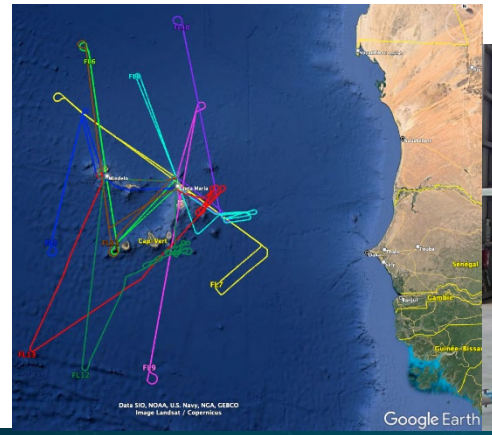


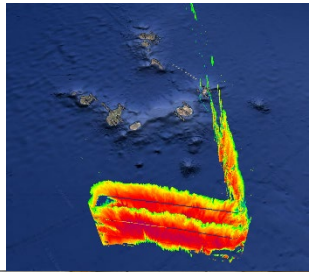
courtesy ECMWF

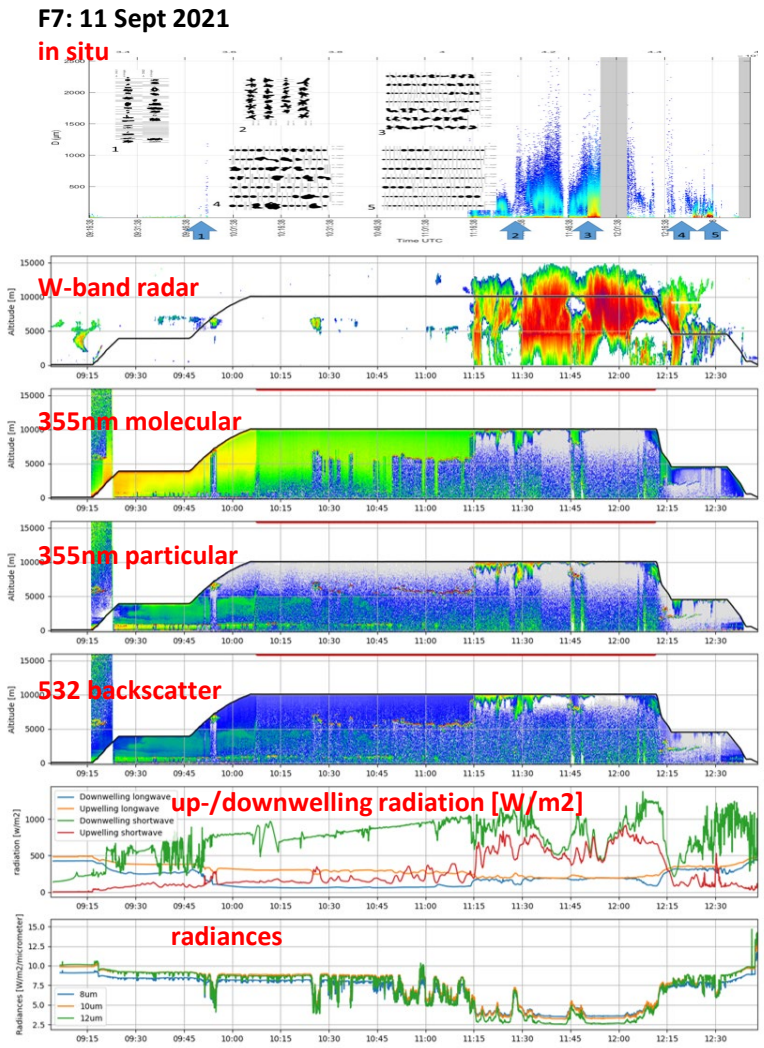
EarthCARE Validation

- 2017 Announcement of Opportunity for EarthCARE validation
  → Validation Portal https://earthcare-val.esa.int/
- Joint ESA-JAXA Validation Implementation Plan
- EarthCARE Validation Workshops (2018, 2021, 2023)
- Preparations are currently ramping up (confirm/identify funding…)
- Campaigns: recent highlight “Joint Aeolus Tropical Atlantic Campaign” JATAC in Cape Verde (Sept. 2021)
  → LATMOS Falcon Flights: radar & lidar, in-situ, radiometry









→ ATMOS 2021 - ESA ATMOSPHERIC SCIENCE CONFERENCE

JATAC / CADDIWA images & quick looks courtesy LATMOS

Acknowledgments

The EarthCARE Joint Mission Advisory Group

Co-chairs: *A.J. Illingworth, H. Okamoto*

Members: *L. Baldini, A. Battaglia, H. Chepfer, N. Clerbaux, J. Cole, J. Delanoë, D. Donovan, J. Fischer, S. Groß, R. Hogan, T.Y. Nakajima, T. Nishizawa, Y. Ohno, M. Satoh, K. Suzuki, N. Takahashi, U. Wandinger*

Observers: *S. Kato, G. Stephens, B. Stevens, D. Vane, D. Winker*

A. J. Illingworth *et al.*

The EarthCARE satellite: The next step forward in global measurements of clouds, aerosols, precipitation and radiation

http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-12-00227.1

Meet us at the Living Planet Symposium, May 2022
Two EarthCARE Sessions!

Level 2 Team

- **ATLID retrievals**
  G.-J. van Zadelhoff, D. Donovan(KNMI, Netherlands)
- **CPR products**
  P. Kollias, B. Puigdomenech (McGill University, Canada); A. Battaglia (University of Torino, Italy)
- **MSI retrievals**
  A. Hünerbein, S. Bley (TROPOS, Germany); N. Docter, R. Preusker, J. Fischer (Free University of Berlin, Germany)
- **BBR radiances and estimated fluxes**
  N. Clerbaux, A. Velazquez, E. Baudrez (Royal Meteorological Institute Belgium); Carlos Domenech, R. Garcia Maranon (GMV Madrid), J. Fischer (Free University of Berlin, Germany)
- **Synergistic ATLID & MSI retrievals**
  U. Wandinger, A. Hünerbein, M. Haarig (TROPOS, Germany)
- **Synergistic CPR & ATLID & MSI retrievals**
  R. Hogan, S. Mason (ECMWF, UK); J. Delanoë, A. Irbah (LATMOS, France)
- **Radiation products (from retrievals) & closure**
  H. Barker, J. Cole, M. Shephard, Z. Qu (Environment and Climate Change Canada); N. Villefranque (LMD/IPSL, France)

ECMWF Assimilation

M. Janiskova, M. Fielding